THE HETCH HETCHY WATER SUPPLY OF THE CITY OF SAN FRANCISCO[1]

By M. M. O'Shaughnessy[2]

The Hetch Hetchy Water Supply project of the City of San Francisco is designed to furnish ultimately a daily supply of 400,000,000 gallons or more to the metropolitan district surrounding the bay of San Francisco.

The source of this water is the higher portion of the watershed of the Tuolumne River, in the Sierra Nevada Mountains, where floodwaters will be impounded in reservoirs for transmission by gravity through two mountain ranges and across two broad valleys to a region whose population is expected to pass the 4,000,000 mark within a century (see fig. 1).

As a water supply system, the project is of greater magnitude than any similar development in the United States except the Catskill supply of New York City and the Metropolitan System of Boston. But it surpasses these in being capable of developing also hydroelectric power, to the extent of over 200,000 horsepower.

Though power is a by-product of the water development, the construction work so far undertaken has been limited to that necessary to put in service the first large power generating station. The reasons for this policy will be given later.

PRESENT WATER SUPPLY OF SAN FRANCISCO

The city's earliest supply of water came from wells and springs close to the original settlement near the northerly tip of the peninsula. As the increasing population began to require a greater supply than these sources could produce, additional water was brought in barges from Marin County across the bay, and distributed by water carts.

During the fifties the systematic development of the present water system was begun by two companies. In 1862 these concerns con-

[1] Presented before the Philadelphia Convention, May 16, 1922.

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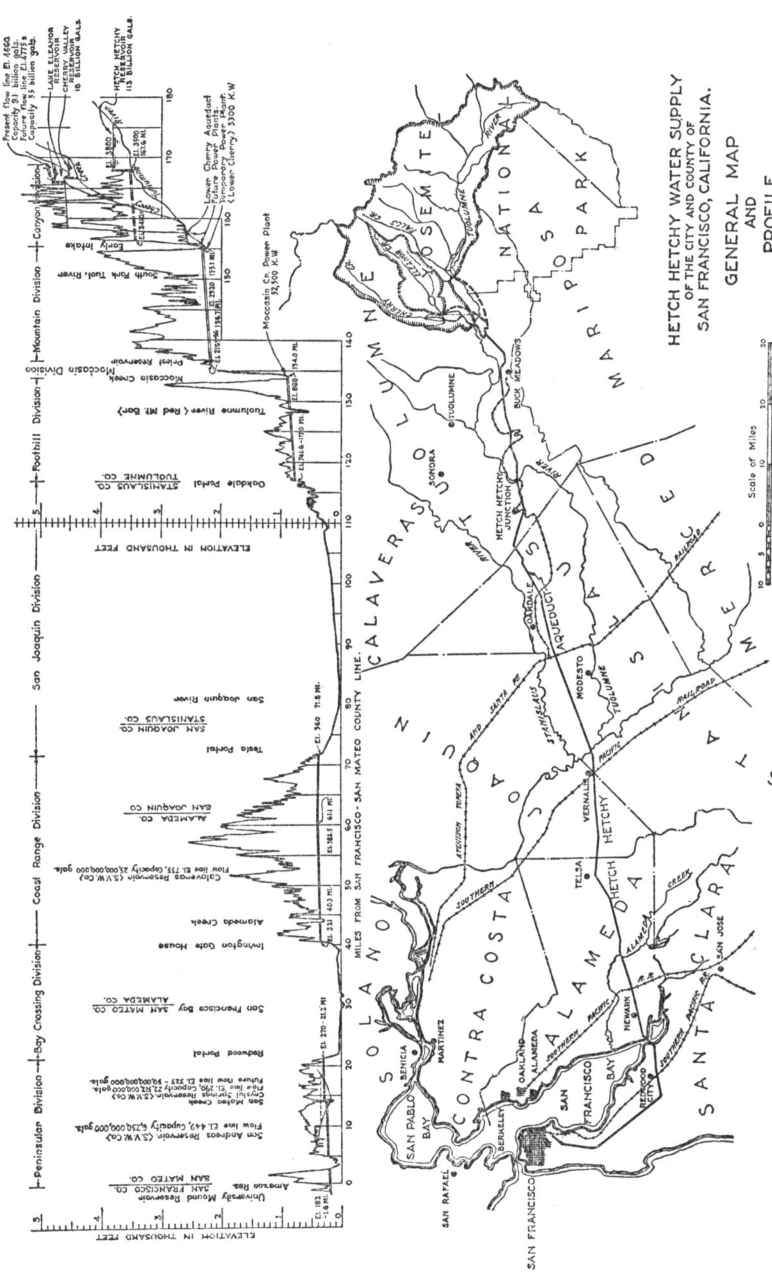

HETCH HETCHY WATER SUPPLY
OF THE CITY AND COUNTY OF
SAN FRANCISCO, CALIFORNIA.
GENERAL MAP
AND
PROFILE
Scale of Miles
ELEVATION IN THOUSAND FEET
MILES FROM SAN FRANCISCO - SAN MATEO COUNTY LINE.
Peninsular Division
Bay Crossing Division
Coast Range Division
San Joaquin Division
Foothill Division
Mountain Division
Canyon Division
Moccasin Division
SAN FRANCISCO
SAN PABLO BAY
SAN FRANCISCO BAY
CONTRA COSTA
ALAMEDA
SANTA CLARA
SAN JOAQUIN
STANISLAUS
TUOLUMNE
CALAVERAS
MARIPOSA
MERCED
SOLANO
YOSEMITE NATIONAL PARK
HETCH HETCHY AQUEDUCT

FIG. 1.

solidated under the name of Spring Valley Water Works, which in 1903 was changed to Spring Valley Water Company.

The first real "water works" began in 1858 to deliver water from Lobos Creek within the present city limits. This, as well as some other sources within the city, have long been abandoned.

The next step was southward to the wooded watershed of Pilarcitos Creek in San Mateo County. Here a dam was constructed, and by means of an aqueduct combining one mile of tunnels, 30 miles of flumes and one mile of riveted wrought iron pipes, the delivery of 2,000,000 gallons a day was begun in 1862. Six years later, pipe was substituted for the greater part of the flume line.

By 1888, two additional reservoirs had been developed by building the Crystal Springs and San Andreas dams. This brought the development of the peninsula supply practically to the economic limit.

Alameda Creek, across the bay, had already been adopted as a source of additional water, and has furnished nearly all increments of supply since 1888. The Calaveras dam, which is not yet completed but is already in use, is located on one of the principal tributaries of this creek. Calaveras reservoir is the most distant part of Spring Valley Works, being about 50 miles from San Francisco along the conduit lines.

The average daily supply from the Spring Valley Water Company's sources in 1921 was 36,338,000 gallons.

The three peninsula reservoirs have an aggregate capacity of about 30 billion gallons. The tributary watershed is 35.3 square miles, of which 31.4 square miles is owned by the Company.

The average daily supply to the city from Spring Valley sources is about 36 m.g.d., of which 15 m.g.d. is from the peninsula reservoirs and 21 m.g.d. from Alameda Creek. Completion of the Calaveras development will increase the total dependable supply to 60 m.g.d.

Besides the Spring Valley supply, a large number of wells within the city limits yield about 8 m.g.d., most of which is used for industrial purposes where cheapness is more important than quality.

HISTORY OF THE HETCH HETCHY PROJECT

About fifty years ago the City of San Francisco began to entertain the idea of municipal ownership of its water supply. The first investigations with a view to municipal control were made in 1871.

The principal source of supply at that time was the peninsula watershed of the Spring Valley Water Works.

Several times between 1871 and 1900, municipal ownership of the water supply was agitated, but each time the water company forestalled the city's action. About the beginning of the present century, however, the public began to realize that for the expansion of the supply necessary in order that the city's growth might continue unhampered, it would be essential to develop new sources.

In the year 1900 the city's present charter was adopted. In this charter there is a clause which in effect declares it to be the policy of the city to own its water works. Pursuant to this provision, the Board of Supervisors directed the City Engineer to make an exhaustive study of the subject of additional water supply, taking into consideration all available sources and the future needs of the city.

As the result of the ensuing investigations, the Tuolumne River was selected as the best.

These studies were made in the years 1900, 1901, and 1902. In 1901 the mayor filed notices of appropriation of water on the Tuolumne River, at Hetch Hetchy Valley, and on Eleanor Creek near the site of the present Lake Eleanor Dam.

Hetch Hetchy and Lake Eleanor had been suggested as sources of water supply for San Francisco as early as 1879 by the State Geologist of California, and Hetch Hetchy in 1891 by the United States Geological Survey.

Surveys were begun in 1901 for reservoirs at Hetch Hetchy Valley and Lake Eleanor and for the aqueduct to San Francisco, and on July 28, 1902, the City Engineer filed a report in considerable detail, with maps and plans of proposed structures.

In November, 1901, occurred the first election of the series which resulted in bringing the government of San Francisco into national disrepute. Corporate interests were during all this time looking with much disfavor upon the city's municipal ownership program and the combination of hostile corporations and a number of city officials amenable to suggestions from the corporations, resulted in holding up progress on the project for several years. At last the grafting officials were thrown out of office, and under the new regime the movement for the additional water supply took fresh impetus, and the Board of Supervisors definitely committed itself to the acquisition of the water supply from the Tuolumne River.

As Hetch Hetchy Valley and Lake Eleanor lie within the boundaries of the Yosemite National Park, it was now necessary to enter into negotiations with the government authorities.

On May 11, 1908, Secretary of the Interior Garfield authorized the city to use Hetch Hetchy Valley as a reservoir site in connection with other works on branches of this river, stipulating, however, that the city should develop the Lake Eleanor site to its full capacity before beginning the development of Hetch Hetchy. Thus the city was to be compelled to develop first the smaller and less desirable source, although this arrangement was certain to be much more expensive than if Hetch Hetchy were to be taken first. The bargain was accepted as the best arrangement that could be reached at that time. It was, however, unsatisfactory, being revocable at any time by the Secretary of the Interior.

In the fall of 1908, the voters of the City authorized an issue of $600,000 of bonds for acquiring lands and water rights. Additional work on plans and surveys was entered upon and on January 4, 1910, the people by a 20 to 1 vote, authorized $45,000,000 worth of bonds for construction.

Thus, at the beginning of 1910, the way was paved for the commencement of preliminary construction work. But on February 25 Mr. Garfield's successor as Secretary of the Interior, R. A. Ballinger, called upon the city to show cause why the Hetch Hetchy reservoir site should not be eliminated from the terms of the 1908 permit. This elimination would have limited the possibilities of the Tuolumne project to such an extent that it probably would have become preferable to abandon it entirely and resort to some one of the sources that had been previously rejected as less desirable and more costly.

There now ensued a dispute of nearly four years duration. Working against the city under cover, and inspiring the greater part of the opposition, were powerful financial interests. The open resistance came from the irrigation districts which derive their water supply from the Tuolumne River and from so-called "nature lovers" apprehensive of desecration of the natural beauty of the Yosemite National Park. Much of this latter opposition was due to an erroneous identification of the Yosemite Park, within whose boundaries part of the project lies, and the Yosemite Valley, which lies within the park, but on another river eighteen miles to the south. Many promoters of rival schemes for supplying water to San Francisco aided the opponents of the Hetch Hetchy plan.

The city's vigorous protest against the proposed withdrawal of its rights in Hetch Hetchy brought about the appointment of a board of engineers selected from the Corps of Engineers of the United States Army to study the matter of additional water supply for San Francisco. About the same time, the city engaged Mr. John R. Freeman as consulting engineer to assist in presenting its case.

The work of both Mr. Freeman and the Army Board confirmed the earlier judgment of the City's engineers in pronouncing the Tuolumne the most available source of additional water supply, not only for San Francisco, but for the San Francisco Bay metropolitan region.

The Army Board submitted its report to the Secretary of the Interior February 19, 1913. By this time the municipal officials had reached the conclusion that nothing short of a special act of Congress would make the City independent of the changing moods of successive Interior Department executives. Accordingly, in 1913, the city secured the introduction before Congress of a bill to grant certain well defined permanent rights in the public lands, covering reservoir privileges, rights of way for aqueducts and power lines, etc.

The opposition carried its fight through both houses of Congress, and even beyond, urging the President to veto the bill, which, however, was signed and became effective December 19, 1913.

Terms of the congressional grant

The Hetch Hetchy development is now being carried forward under the authority of the act of Congress of 1913, the principal provisions of which are in substance as follows:

The City and County of San Francisco is granted lands in the Hetch Hetchy Valley, the Lake Eleanor basin, and Cherry Valley, for reservoirs, and lands and rights of way elsewhere in the public lands, for aqueducts, power plants, power transmission lines, roads, railroads, telephone lines, etc.

The City is empowered to enforce sanitary regulations within the water shed tributary to the reservoirs and aqueduct.

The City is required to recognize the prior right of certain irrigation districts of the San Joaquin Valley to receive from the natural flow of the Tuolumne River such water as can be beneficially used by them, up to specified maximum quantities. This entails no obligation to store water for irrigation, but merely reduces the amount that the City may retain in storage or divert for its own purposes out of the quantity entering its reservoirs, when the quantity of water entering the Tuolumne below the City's dams is less than the irrigation priorities.

The City is not permitted to divert beyond the limits of the San Joaquin Valley any more of the waters of the Tuolumne watershed than, together with the waters which it now has or may hereafter acquire, shall be necessary for its beneficial use for domestic and other municipal purposes.

The City is required to develop electric power for municipal and commercial use, up to a minimum of 60,000 horsepower; to construct and maintain certain roads and trails, and to pay to the United States an annual rental graduated up to a maximum amount of $30,000.

Metropolitan water district contemplated

The provisions of the act are extended to "the City and County of San Francisco and such other municipalities or water district or water districts as may, with the consent of the City and County of San Francisco or in accordance with the laws of the State of California, hereafter participate in or succeed to the beneficial rights and privileges granted by this act."

The laws of the State of California provide for the formation of municipal water districts, through the initiative of the legislative body of any municipality and the subsequent ratification, first by the legislative bodies, and then by a majority of the voters, of all municipalities named by the first one in its initial ordinance. The act contemplates the sale of water at wholesale by the district to its component municipalities, the distribution of the water being left to the latter organizations.

No effective steps have as yet been taken toward the formation of such a district embracing San Francisco and the neighboring cities and towns which would be advantageously served by the Hetch Hetchy aqueduct.

Construction period

Preliminary construction was commenced during 1914, and work has been continuous from that time to the present, though difficulties of financing and obtaining workmen and materials, due to war conditions, greatly retarded the progress of the project. It was only in 1921 that the work was at last running "full blast," without interference due to conditions not originating in the project itself.

The course of construction will be indicated in the subsequent descriptions of the various features of the work.

GENERAL POLICY AND CONSTRUCTION PROGRAM

As a matter of sound business policy, the construction program has been arranged with a view to making available at the earliest possible time the works which can earliest be utilized.

The completion of the entire aqueduct will require several years'

TABLE 1

Statistics of Hetch Hetchy and Lake Eleanor Reservoirs

	HETCH HETCHY RESERVOIR		LAKE ELEANOR	
	Initial	Ultimate	Present	Ultimate
Area of watershed, square miles	459	459	79	183*
Capacity of reservoir:				
Millions of gallons	67,000	113,500	9,100	54,900†
Acre feet	206,000	348,500	28,000	168,400
Water surface area, square miles	2.5	3	1.5	2.2
Elevation of roadway on dam, feet	3,726.5	3,812	4,661	4,785
Elevation of spillway crest, feet	3,719.75	3,800	4,660‡	4,775
Length of reservoir, miles	7.5	8	3.1	3.2
Width of reservoir, maximum, miles	0.65	0.7	1.0	1.1
Width of reservoir, average, miles	0.33	0.38	0.5	0.7
Depth of reservoir from spillway crest:				
Maximum, feet	220	300	60†	175†
Average, feet	129	179	29†	119†
Dam:				
Type of dam	Concrete, gravity section arched in plan		Reinforced concrete buttressed arch	Rock fill with concrete facing
Length on crest, feet	600	900	1,260	1,750
Height of crest above stream level, feet	226 (Roadway)	312 (Roadway)	60	185 (Roadway)
Depth from stream level to bedrock at upstream, maximum, feet	101	101	Stream bed is solid rock	
Depth from stream level to lowest point in foundation, feet	118	118		
Height of dam above bedrock at toe, maximum, feet	327	413	61	
Height of dam above lowest point in foundation, feet	344	430	70	
Width at crest, feet	15	25		
Width at base, maximum, feet	298	298		
Volume of masonry, cubic yards	375,000	625,000	11,640	
Type of spillway	Siphon	Channel around end of dam	Overflow	Channel around end of dam

* Includes Cherry watershed above proposed diversion.

† Lake Eleanor depths and capacities do not include that portion of the original lake which is not available for draft.

‡ With flashboards in place; 4,655 without flashboards.

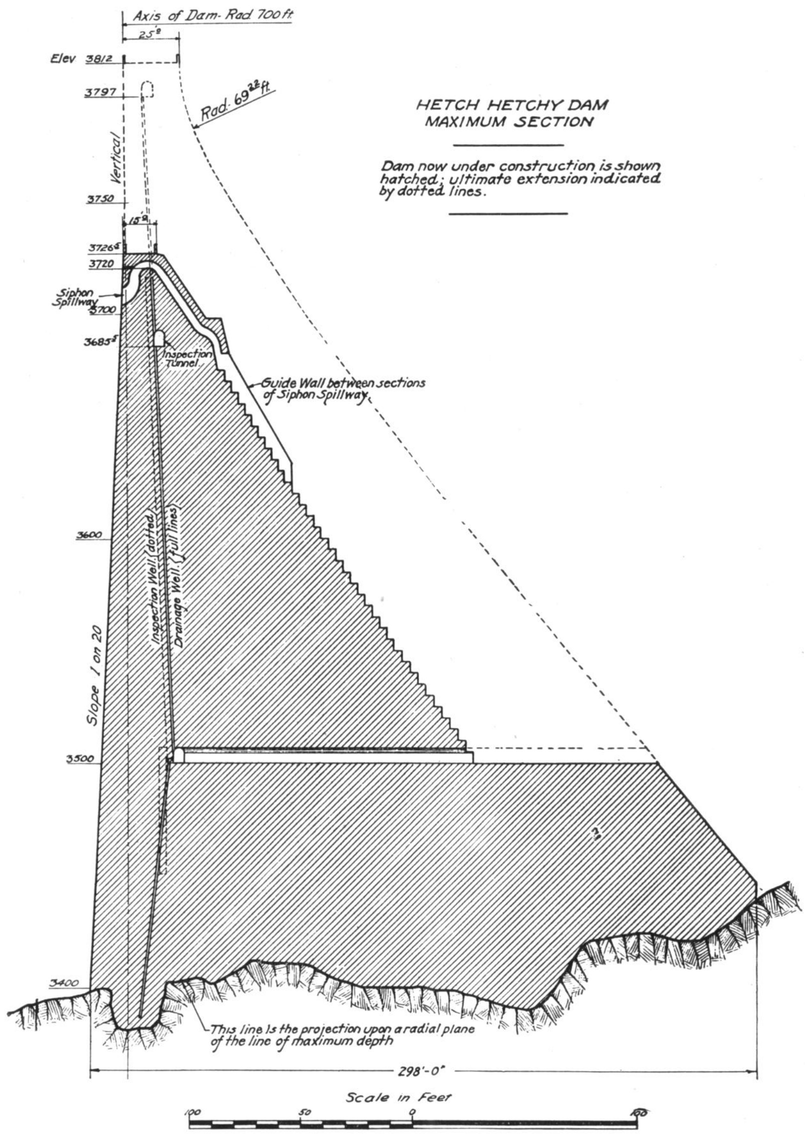

Axis of Dam-Rad 700 ft
25'0"
Elev 3812
3797
Rad. 69.22 ft
HETCH HETCHY DAM
MAXIMUM SECTION
Dam now under construction is shown hatched; ultimate extension indicated by dotted lines.
Vertical
3750
15'0"
3726.5
3720
Siphon Spillway
3700
3685.5
Inspection Tunnel
Guide Wall between sections of Siphon Spillway
3600
Inspection Well (dotted)
Drainage Well (full lines)
Slope 1 on 20
3500
3400
This line is the projection upon a radial plane of the line of maximum depth
298'-0"
Scale in Feet
100
50
0
100

FIG. 2

time and a great expenditure of money. The full development of the local supply system of the Spring Valley Water Company will yield sufficient water to take care of the city's needs for ten years or more, so there is no need for haste in bringing in Hetch Hetchy water.

The policy therefore has been to concentrate all resources upon the construction of the portions of the system necessary for the development of the first large hydroelectric power plant, which is now expected to be in operation in about two years. The revenue from power sales will then be applied toward the payment of bond interest and redemption charges, materially lightening the financial burden upon the taxpayers.

The next unit to be undertaken is the construction of the portion of the aqueduct extending from the Spring Valley Water Company's Alameda County sources to San Francisco. The Company's present pipe lines have not sufficient capacity to convey the additional supply which its sources will produce, and rather than permit the company to build an additional conduit, the city will build this link of the Hetch Hetchy system in the near future and rent it to the Company.

The construction of the connecting links across the San Joaquin Valley and the Coast Range Mountains will be deferred until after the completion of the immediately essential parts.

DAMS

There are to be two principal storage reservoirs, Hetch Hetchy and Lake Eleanor, of which some characteristics are given in Table I.

The Hetch Hetchy dam

This dam is located on the Tuolumne River, at the lower end of Hetch Hetchy Valley. It is a concrete dam of the gravity type, and is to be built in two installments (see fig. 2). The first installment, now under construction, will have a height of 226 feet above the original stream bed, and will impound 67 billion gallons of water. The foundation already built, up to the stream bed level, has a maximum depth of 118 ft. below the original stream bed, and is designed to support the ultimate structure, which will stand 312 feet above stream bed and impound 113.5 billion gallons of water.

During the construction of the dam, the Tuolumne River is being diverted from the site through a tunnel, 25 feet wide, 23 feet high and 900 feet long.

The Hetch Hetchy Dam is being built by the Utah Construction Company, under contract, at an estimated total cost of $5,447,792.

Concrete is being placed at an average rate of over 1000 cubic yards daily. The record day's pour so far made is about 1550 cubic yards. The work was contracted for on August 1, 1919, and is expected to be completed in February, 1923.

FIG. 3. HETCH HETCHY DAM SITE—DOWN STREAM FROM ELEANOR ROAD

Outlet system of the Hetch Hetchy dam. The outlet system of the Hetch Hetchy Dam comprises two sets of outlet conduits. One set will be used to discharge water to satisfy the prior claims of irrigators on the lower Tuolumne River. The other set will discharge water to be delivered to the aqueduct.

The valves regulating the quantity of water released into these conduits will be balanced needle valves of the Larner-Johnson type, manufactured by the Cramp Ship and Engine Building Company of Philadelphia.

The balanced valves for irrigation water control will be 6 in number, each 5 feet in diameter. They will be set into the sides of two wells, two at each of three different elevations, and will discharge into 5-foot conduits terminating in the downstream face of the dam. Ahead of each of the balanced valves will be a steel slide gate, hydrauli-

cally operated. The gate valves will not be used to control the flow, but only to shut it off entirely for access to the balanced valves.

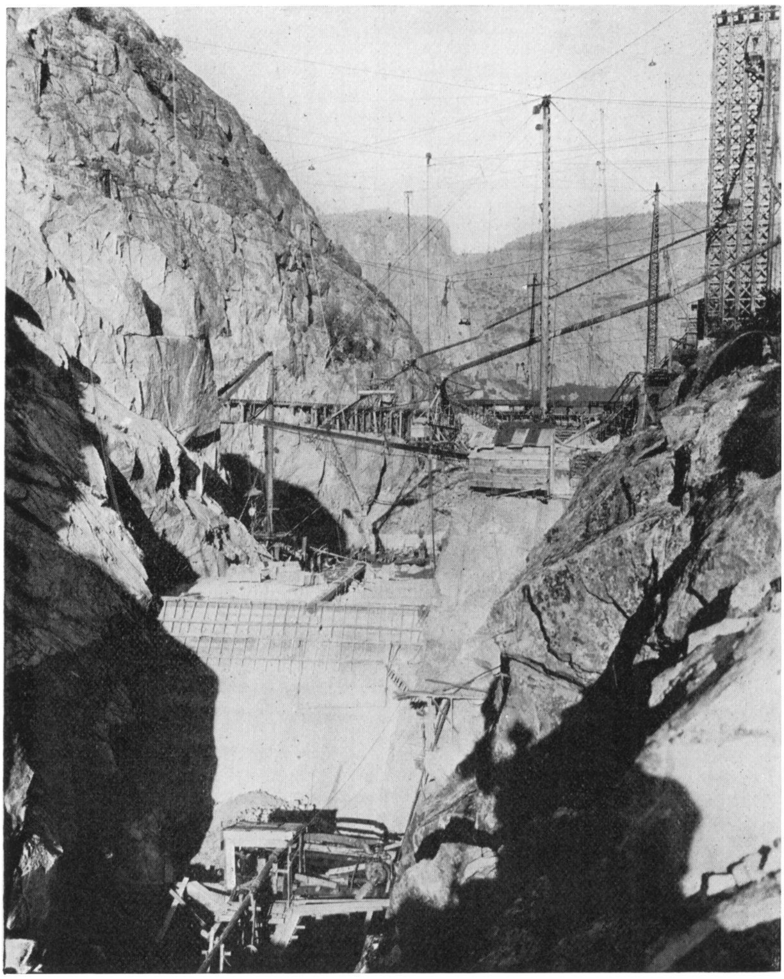


FIG. 4. POURING CONCRETE IN HETCH HETCHY DAM, NOVEMBER, 1921. UPSTREAM VIEW

Ahead of the slide gates will be heavy concrete shutters, which can be let down in vertical slots, and which will shut out the water from the gate valves in case the latter require inspection or repair.

To discharge water into the future aqueduct tunnel that will extend from the dam to Early Intake, six three-foot balanced valves will be installed in six conduits, three extending through the body of the dam, at elevation 3625, the other three passing through a concrete plug to be constructed in the existing diversion tunnel, at elevation 3508.

TABLE 2

Power development possibilities

	EXISTING PLANT	PROPOSED PLANTS		
Location of plant	Early Intake	Moccasin Creek	Early Intake	North Mountain
Source of water supply	Cherry River	Hetch Hetchy Reservoir	Hetch Hetchy Reservoir	Lake Eleanor
Aqueduct, type	Flume, canal and tunnel	Pressure tunnel	Pressure tunnel	Canal and tunnel
Aqueduct length, miles (not including pressure pipes)	3.3	19.5	11	7.6
Aqueduct capacity, second feet	200	620	620	200
Forebay, type	Large flume	Reservoir		
Forebay, capacity:				
Gallons	1,500,000	815,000,000		
Acre-feet	4.6	2,500		
Pressure pipes:				
Length, feet	530	4,345	2,500	5,700
Number of pipes	1	4		
Diameter of pipes	3′6″			
Gross drop, feet	345	1,315	1,100	2,000
Power plant:				
24-hour average capacity at power factor 1.00 K. W	3,000	52,500	42,000	24,000
H. P.	4,000	70,000	56,000	32,000
Generators: Number	3	4*		
Capacity each machine, K.W.	1,100	17,500		
Total installed capacity, K.W	3,300	70,000*		
H. P.	4,400	94,000*		

Note:—Development of Huckleberry and Emigrant Lakes as reservoirs will make available additional power, the amount of which has not yet been determined.

* Initial installation. Additional generators to be installed later.

Lake Eleanor dam

Lake Eleanor as a reservoir will be second to Hetch Hetchy, but has already been developed to a capacity of 9 billion gallons, which is about one-sixth of the ultimate proposed capacity. This was done in order to provide water to operate the Lower Cherry power system during the months of low stream flow.

The dam extends across the canyon of Eleanor Creek nearly a mile downstream from the original lake. It is of the buttressed arch type, built of reinforced concrete, and will ultimately be incorporated into a higher structure. It is 1260 feet long, and has a 200-foot spillway. The water is withdrawn through two 24-inch sluice valves on the face of the dam. In addition, there are two 24-inch scouring valves near the bottom of the dam.

Construction of the dam was begun September 1, 1917 and completed late in 1918, entirely by day labor, at a cost of about $290,000.

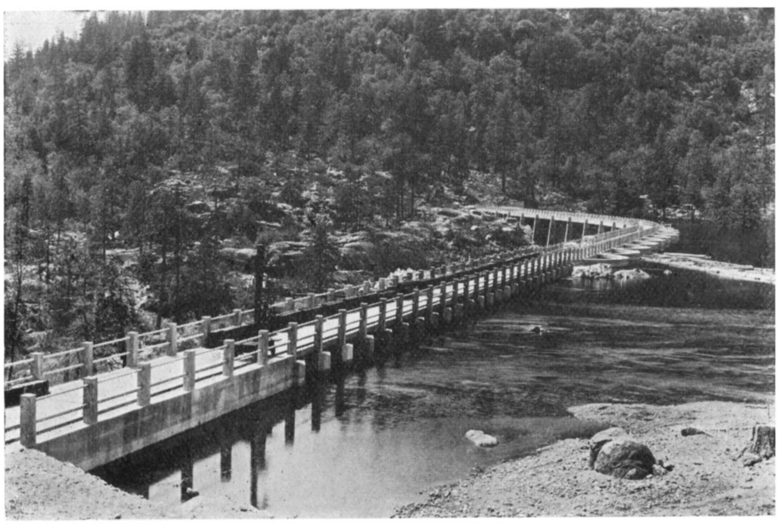


FIG. 5. ELEANOR DAM UNDER CONSTRUCTION, AUGUST, 1918

A diversion dam is to be built on Cherry Creek, about ten miles above its junction with Eleanor Creek. By means of a diversion conduit, about 5 miles long, upper Cherry Creek will be made tributary to Lake Eleanor.

POWER DEVELOPMENT

The entire scheme includes four hydroelectric power plants; one completed, at Early Intake, and three to be built, at Moccasin Creek, Early Intake, and North Mountain. Specific data concerning the four power plants are given in table 2.

A temporary power plant at Early Intake was put into operation in 1918. This plant generates power for the building of the Hetch

Hetchy dam, the tunneling operation, on the 18.3 mile aqueduct now under construction, lighting of the construction camps and the town of Groveland, etc. During the greater part of the year suffi-

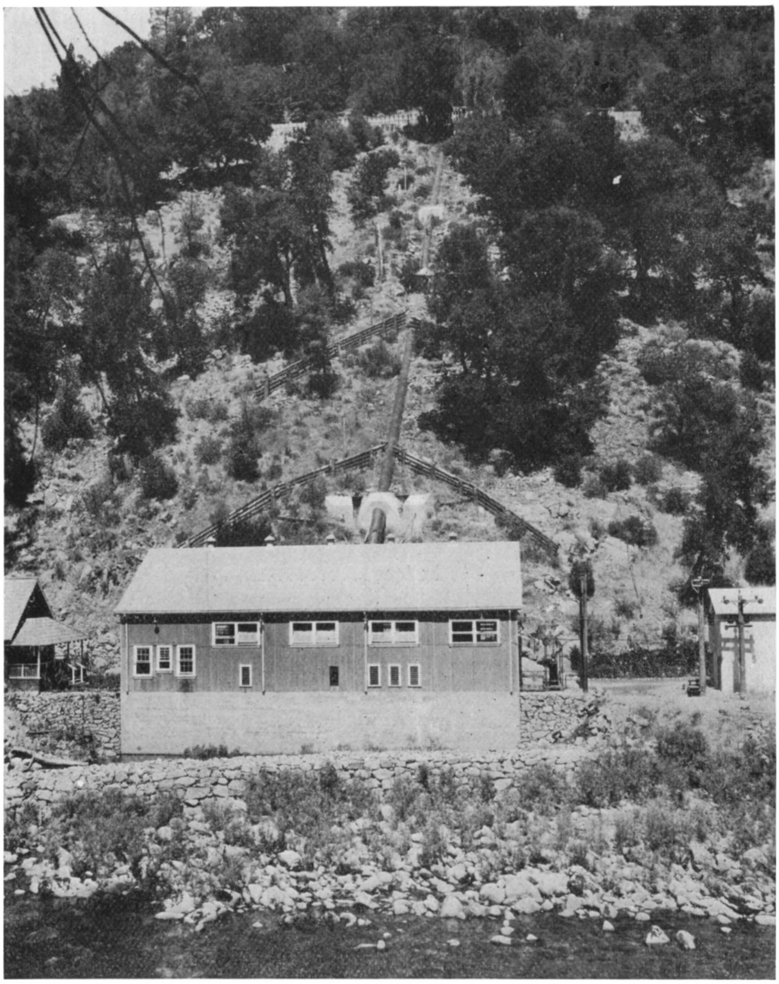


FIG. 5a. TEMPORARY POWER PLANT AT EARLY INTAKE ON THE TUOLUMNE RIVER.

cient water is available to generate more power than the construction work demands. The surplus is then sold to the Pacific Gas and Electric Company, through a connection at Priest.

The water for this plant is supplied from the Cherry River, to which Eleanor Creek is tributary, through a conduit about $3\frac{1}{2}$ miles long, which is to be a permanent feature of the Hetch Hetchy System. After the usefulness of the power plant is over, the conduit will contribute Cherry River water to the main aqueduct, which heads at Early Intake.

TABLE 3

Properties of standard lined and unlined tunnel sections

	LINED	UNLINED
Dimensions:		
Area inside of prescribed line, in square feet	105.63	167.8
Area inside of lining (A), in square feet	87.94	
Area of concrete inside of prescribed line in square feet	17.69	
Excavation inside of prescribed line, in cubic yards per lineal foot	3.912	6.21
Concrete inside of prescribed line, in cubic yards per lineal foot	0.655	
Perimeter, inner side of lining (p) in feet	33.79	
Hydraulic Elements:		
Wetted perimeter (p), in feet	33.79	48.0
Hydraulic radius $\left(r = \frac{A}{p}\right)$, in feet	2.60	3.5
Hydraulic slope (s)	0.00121	0.00118
Coefficient of roughness in Kutter's formula (n)	0.014	0.032
c, in Chezy formula	125.5	57.4
Velocity of water ($v = c\sqrt{rs}$), in feet per second	7.04	3.69
Quantity of water flowing ($Q = A\ v$), in cubic feet per second	619	619

About 20 miles below Early Intake, on the Hetch Hetchy aqueduct line, is the site of the Moccasin Creek Power Plant, which will be the first large unit of power development. It will receive water through the tunnel now under construction from Early Intake, and discharge into a lower section of the aqueduct, to be constructed later.

Topography does not favor the construction of regulating reservoirs above the penstocks of the two other future power plants, and therefore it is planned that in the finished system, they will be operated at constant outputs, and the entire load fluctuation of the system will be absorbed by the Moccasin Creek plant, where an

unusually large forebay reservoir is being provided, as described later.

The Early Intake power plant will be located on the Tuolumne River, 12 miles below the Hetch Hetchy dam. The fall of the water from the reservoir will be conserved by leading it through a tunnel in the canyon wall south of the river from the dam to a point near the power house. Until this unit is completed, the water from the Hetch Hetchy reservoir will flow in the bed of the Tuolumne River to Early Intake.

The North Mountain power plant site is on the Tuolumne River, a short distance above the Early Intake plant. The plant will be supplied with water from Lake Eleanor through a conduit about $8\frac{1}{2}$ miles long, and will discharge into the Tuolumne above the Early Intake diversion, thus making Lake Eleanor tributary to the main aqueduct.

THE AQUEDUCT

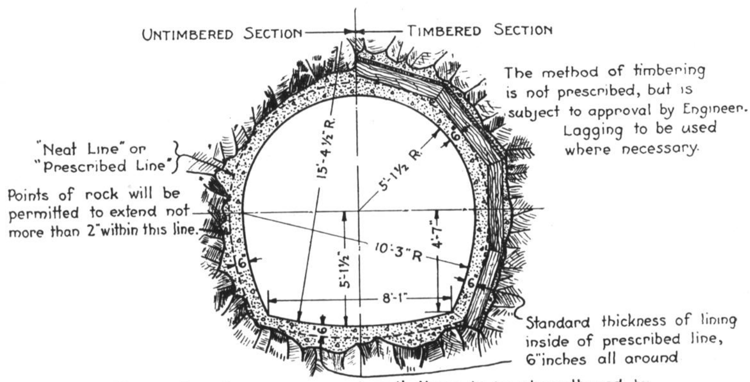
The Mountain Division of the aqueduct begins at Early Intake, where the water, first from Hetch Hetchy, and later also from Lake Eleanor, will be turned by a diversion dam from the river into a tunnel, 18.3 miles long. Standard lined and unlined sections of the tunnel are shown in figures 6 and 7, and their dimensions and hydraulic properties listed in table 3. The unlined section is used for about six miles of the total length, in which distance the rock encountered is very hard and sound. Fifty-nine per cent of the tunnel excavation is now completed. (March, 1922).

At the lower end of this division is the Priest Reservoir, which is the forebay for the Moccasin Creek power house. The reservoir will be formed by building an earth and rock fill dam, 145 feet high, containing about 800,000 cubic yards, with a concrete core wall, across a small gulch. The capacity of the reservoir will be 800,000,000 gallons, or two days flow of the aqueduct at its maximum capacity. The dam is now under construction. The major part of the earth fill is to be placed by hydraulic sluicing.

After being discharged from the Moccasin Creek power house, the water will enter a tunnel similar to the one above, and continue underground for 17 miles, to Oakdale Portal.

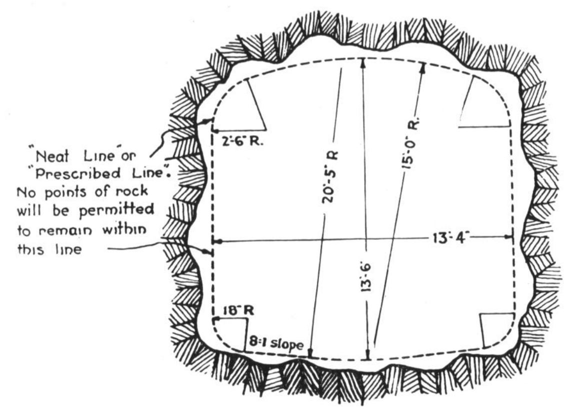
Pressure tunnels

The Hetch Hetchy aqueduct is unique in its use of long tunnels operating under pressure. The tunnels are placed 20 to 70 feet below the hydraulic grade line and will flow full. The slope of the



Where external pressure requires it, lining to be strengthened by increasing the thickness of concrete or adding steel reinforcement or both
Standard Lined Tunnel Section

Figure 6



Standard Unlined Tunnel Section

Figure 7

hydraulic grade line is less than that of the tunnel itself, the two rates being, in the tunnel from Early Intake to Priest reservoir, 0.0012 and 0.00155, respectively. As the flow capacity of an aqueduct can not be predicted with a great degree of certainty, prudence requires the designer to anticipate the worst conditions, where the

aqueduct is to be constructed at once of its full ultimate size. Thus there is always a probability that the actual conditions will be better than those assumed in design. When the aqueduct is operated under pressure, if the actual loss of head in any section is less than that assumed, the difference may be advantageously used in other sections of the development. This would not be possible with conduits located at hydraulic grade. In the Early Intake—Priest tunnel, each foot of head so conserved will operate to increase the power output of the Moccasin Creek plant by about 55 horsepower.

San Joaquin Valley crossing

The San Joaquin Valley will be crossed by steel pressure pipes, extending 45 miles from Oakdale portal to Tesla portal. To develop the ultimate capacity of 400 million gallons per day, three pipes of about seven feet diameter will be required. The detailed plans for this section and for the Coast Range tunnel have not been definitely fixed, and the program of construction will be partly determined by the action of the municipalities around San Francisco Bay in the matter of forming a water district.

The Coast Range will be penetrated by pressure tunnels, 31.5 miles from Tesla Portal to Irvington Gate House, broken by a steel siphon crossing the canyon of Alameda Creek. The hydraulic grade rate of this tunnel will be less than the slope from Moccasin Creek to Oakdale Portal, the tunnel cross-section being made larger than in the Sierra Nevada.

Distribution

At Irvington Gate House, ten miles east of the Bay, water for destinations other than the San Francisco peninsula will be diverted from the main aqueduct into branch conduits not yet planned. The pipes and tunnels connecting Irvington Gate House and San Francisco are being designed for an ultimate capacity of 200,000,000 gallons daily.

From Irvington Gate House across San Francisco Bay and the adjacent low lands to Redwood Portal will be about 20 miles of pipe. The line crosses the bay at Dumbarton Strait, whose width is 1.3 miles, and maximum depth 50 feet. The ultimate development here will require three pipes, each over six feet in diameter. A 5-foot pipe will be used for the initial stage.

From Redwood Portal to San Francisco the aqueduct will consist of alternating sections of tunnel and pipe, totaling about 20 miles. In order that a large supply of water may always be available in storage near San Francisco, connection is to be made from the tunnel to the Crystal Springs Reservoir of the Spring Valley Water Company near Redwood Portal.

Within the city limits will be the Amazon Receiving Reservoir, the terminus of the aqueduct. Its capacity will be 300 million gallons, and its high water elevation 248 feet above sea level. About half the total city supply will be distributed from this reservoir by gravity.

The aqueduct from the east side of the bay to Crystal Springs Reservoir is the section which, as before noted, is to be constructed in the immediate future to make available the additional water supply from local sources. It will receive water from the Spring Valley Water Company's conduit near Irvington. The existing pipe lines between Crystal Springs Reservoir and San Francisco are capable of carrying more water than they now receive, permitting deferring construction of the parallel Hetch Hetchy aqueduct.

AUXILIARY WORKS

Besides the temporary power plant already mentioned the City carries on several other auxiliary enterprises developed preliminary to the construction work.

Hetch Hetchy Railroad

Most important of these is the Hetch Hetchy Railroad, which was built during the period 1915–1918, to transport construction materials to the Hetch Hetchy Dam and the easterly divisions of the aqueduct. It is a standard gage railway, 68 miles long, extending from the dam to Hetch Hetchy Junction, at which point it connects with the Sierra Railway of California. The latter connects with the Southern Pacific and the Santa Fe railroads at Oakdale, 26 miles from Hetch Hetchy Junction.

From Hetch Hetchy Junction, the railroad extends easterly to the Tuolumne River. It follows the river to Moccasin Creek, and from there follows a ridge route, ascending from an elevation of 700 feet at Moccasin Creek, to a summit at elevation 5064, and descending again to elevation 3870 at its terminus near Hetch Hetchy

Dam. The road is operated as a common carrier. Besides its principal function of transporting materials for the dams and aqueducts, it carries passengers and hauls some lumber and general freight for parties not connected with the project.

Sawmill

The city operates a sawmill at Mather, nine miles below Hetch Hetchy on the Tuolumne River. The mill was first constructed in 1915, but was moved in 1920 to its present location. Yellow

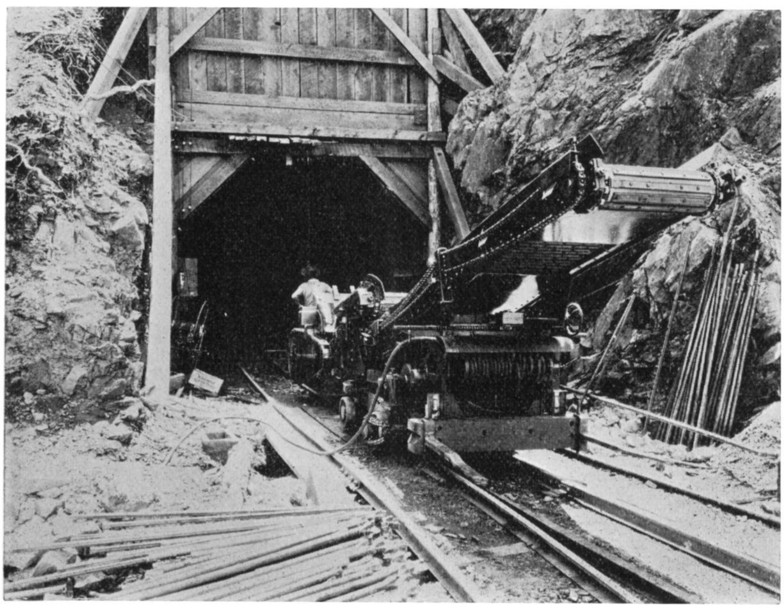


FIG. 8. PORTAL OF HETCH HETCHY AQUEDUCT TUNNEL, SHOWING MYERS-WHALEY MUCKING MACHINE USED TO REMOVE DEBRIS, AUGUST, 1921

pine, sugar pine, red fir and cedar are cut within a radius of about a mile from the sawmill, and hauled to the mill with donkey engines and cables. The capacity of the mill is 25,000 to 30,000 feet per 8-hour shift. Over 10 million feet of lumber have been sawed since the mill was established at Mather. All lumber used on the project was produced at this mill, except the redwood and Oregon pine used on the railroad, and the lumber used in building the Lake Eleanor dam. The latter was cut and sawed at Lake Eleanor.

Shops

The city's machine and blacksmith shops and car repair shop at Groveland do practically all the repair work and overhauling of the rolling stock of the Hetch Hetchy Railroad, and also such work on the construction machinery as cannot be handled by the small shops at the various camps.

FIG. 9. CITY SAWMILL AND POND AT MATHER

Medical service

At Groveland the City maintains a hospital, with a physician and 3 nurses. Both industrial and non-industrial casualties are handled by the City's medical service. For service in illness and accident cases not resulting from their employment, the employees are charged $1.00 per month each. For providing service in industrial accident cases, against which it carries insurance with the California State Compensation Insurance Fund, the City is allowed a 15 per cent rebate on the premiums.

ORGANIZATION AND MANAGEMENT

The Hetch Hetchy development is one of the activities of the Department of Public Works of the City and County of San Francisco. The City Engineer is Chief Engineer of the project, and the Chief Assistant Engineer has direct charge of the work.

Two Construction Engineers, located at Groveland and Hetch Hetchy, report to the chief assistant engineer.

Headquarters engineering work is carried on at the City Engineer's office in San Francisco. Field headquarters for the work now in progress are at Groveland, 27 miles by rail from Hetch Hetchy Junction.

The number of employees in the field reached a maximum of 1643 in November, 1921. In February, 1922, the number was 1423, which will be exceeded when the weather conditions permit more rapid work on the various construction units. Total expenditure up to the end of the year 1921 were about $16,500,000. Net expenditures for the fiscal year of 1920–21 were about $3,474,000.

Personnel

The engineering staff of the project includes:

General:
- M. M. O'Shaughnessy, City Engineer of San Francisco, Chief Engineer; N. A. Eckart, Chief Assistant Engineer.

City Office Staff:
- Leslie W. Stocker, Assistant Engineer
- R. P. McIntosh, Hydraulic Engineer
- R. J. Wood, Structural Engineer
- Paul J. Ost, Electrical Engineer
- Edwards P. Jones, Mechanical Engineer

Construction:
- C. R. Rankin, Construction Engineer, Hetch Hetchy Dam.
- Lloyd T. McAfee, Construction Engineer, aqueduct tunnels and Superintendent, Hetch Hetchy Railroad.

The following are among the experts who have acted as consultants on the project.

Mr. John R. Freeman, Civil Engineer.
Mr. Frank G. Baum, Electrical Engineer
Dr. Wm. F. Durand, Mechanical Engineer
Dr. James C. Branner, Geologist
Mr. John D. Galloway, Civil Engineer.
Prof. Charles D. Marx, Civil Engineer.